FIRST *MESSENGER* INSIGHTS CONCERNING THE EARLY CRATERING HISTORY OF MERCURY.
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Introduction: Mercury has long been recognized as a key planet for understanding the early bombardment history of the Solar System, but until early this year the only spacecraft views of its cratered landscape were Mariner 10's vidicon images of 45% of the planet's surface (much of it seen at high solar illumination angles) obtained in the 1970s. Beginning with its first flyby of Mercury in January 2008, the MESSENGER spacecraft will continue through its orbital mission (commencing in March 2011) to image the whole planet from a variety of perspectives. It will also obtain laser altimetry and other important geophysical measurements that will dramatically increase our understanding of the impact history in the inner Solar System and of Mercury's planetary response to the bombardment.

Basins on Mercury: Even from Mariner 10 images, numerous impact basins were identified, although researchers differed on whether or not Mercury is more densely covered with basins than is the Moon [1, 2, 3]. The dramatic Caloris basin, the eastern half of which was revealed by Mariner 10, is one of the largest and youngest multiring impact basins in the Solar System. The entirety of Caloris dominates the new sector of Mercury imaged by MESSENGER during the first flyby (Fig. 1), and Caloris is now measured to have a diameter of about 1,550 km, or more than 200 km larger than estimated from Mariner 10. This makes Caloris roughly the size Borealis (a stratigraphically old basin near the north pole), which previously had been regarded as Mercury's largest basin.

Additional basins, or evidence of possible basins, are seen in the new MESSENGER images. A particularly interesting example is the double-ring (peak-ring) basin, Raditladi. (Raditladi is about 260 km in diameter, somewhat bigger than a somewhat arbitrary dividing line between large craters and small basins, 250 km.) Raditladi appears to be unusually fresh, with a very small density of superposed small craters; it is possible that it formed within the last billion years [4].

As MESSENGER makes its next two flybys of Mercury and eventually enters orbit, high-quality imaging of the entire surface will provide a basis for a more thorough photogeologic assessment of the planet's basins. However, in recent years, other kinds of data sets have been used to assess basin populations on other terrestrial bodies. MGS MOLA topography and gravity data for Mars have revealed many large circular structures, especially in the northern lowlands, which are likely basins [5]. Frey [6] has used the Unified Lunar Control Network (based largely on photogrammetric measurements of Clementine images) to nearly double the number of potential lunar basins assessed by Wilhelms [7]. MESSENGER's Mercury Laser Altimeter should enable a similar advance in recognition of Mercury's basins from precise topography.

Mercury's Bombardment History: Mercury's "Population 1" crater size distribution has been attributed to the same population of impacting bodies responsible for the Late Heavy Bombardment (LHB) on the Moon [8]. ("Population 2" refers to more recent, generally smaller craters not relevant to early bombardment.) Besides the basins, Population 1 includes craters 10 – 250 km diameter in Mercury's more heavily cratered regions. Although crater size-frequency distributions for the more heavily cratered terrains on the Moon and Mars are similar to Mercury's Population 1, there are significant differences among all three bodies [8]. The relative depletion of craters smaller than 40 km diameter on Mars compared with the Moon is reasonably attributed to the wide variety of geological processes that have been, and continue to be, active on Mars. The depletion in numbers of craters smaller than 40 km is even greater on Mercury, which lacks an atmosphere and many of the processes active on Mars. This depletion has generally been ascribed to more pervasive erasure by formation of the so-called intercrater plains, which are stratigraphically timed as having formed during the LHB [9].

There has been debate about the nature of intercrater plains. If they are primarily formed by basin ejecta, like the Cayley plains on the Moon, then why would they be so much more pervasive on Mercury compared with the Moon? Possibly they represent pervasive early volcanism.

As the youngest large basin, Caloris provides insight to issues of plains formation. The formation of at least some of the so-called smooth plains on Mercury has been as controversial as the formation of intercrater plains. Smooth plains are common on the periphery of Caloris in Mariner 10 images. Many researchers considered these plains to be of volcanic origin, although no explicitly volcanic features could be iden-

tified, while others considered the plains to have been formed by Caloris ejecta, like the lunar Cayley plains [10]. Now MESSENGER has found unequivocal evidence that at least some of the plains in the newly imaged region of Mercury are volcanic in nature [11, 12]. Yet many other circum-Caloris plains may be related to basin ejecta. Since these basin-related smooth plains may simply be the most recent, pristine examples of what we classify as intercrater plains when they are much older, final resolution of the relative contributions of volcanism and ejecta emplacement to plains formation will profoundly affect our understanding of Mercury's early bombardment history.

It has been suggested [13] that a cataclysmic bombardment of Mars could have deposited sufficient heat to have affected the thermal evolution of the planet's upper mantle and generated widespread surface volcanism. Due to gravitational focusing by the Sun, comets and asteroids dislodged during a Solar-System-wide LHB, as proposed by the Nice model [14], might have pummeled Mercury with especially energetic impacts, perhaps contributing to a volcanic production of abundant intercrater plains.

Recently it has been suggested [15, 16, 17] that the global dichotomy of Mars was caused by an extremely large impact in that planet's northern hemisphere. Perhaps that happened near in time to the hypothesized giant-impact formation of the Moon and a hypothetical impact that may have stripped away much of proto-Mercury's once-more-massive crust and upper mantle [18]. But these events all surely preceded the LHB, while planetary embryos were still around. Events in this very early epoch may have created geochemical and geophysical attributes of Mercury that can be studied by MESSENGER, but the geological record on the planet's surface likely is restricted to the later phases of the LHB around 3.9 Ga and more recently.

Puzzles remain, however, about the several-million- year period following formation of the last lunar basin, Orientale, when the impact rate was still much higher than it is now, though declining. Meteoritic evidence suggests asteroids were still colliding more often than they are now [19] and post-Caloris impacts may be better preserved on Mercury than they are on other planets if Mercury's global contraction terminated volcanic resurfacing. So comparisons of Hesperian Mars, post-Orientale Moon, and post-Caloris Mercury may help decipher the declining bombardment at and after the end of the LHB epoch in the Solar System.

A lingering complication is the possibility that the intense phase of Mercury's impact history extends to more recent times than for other terrestrial planets because of a hypothetical population of Mercury-specific impactors, called vulcanoids [20]. This would potentially obscure our interpretation of Mercurian cratering as being due solely to the same population of asteroids and comets that have impacted the other terrestrial planets, both during and after the LHB. While Earth-based searches for vulcanoids have constrained the current population to being rather small bodies if they exist at all, vulcanoids could have been largely depleted by now but remained well beyond the end of the LHB [21]. MESSENGER has already taken a few of a planned campaign of images of the outer portions of the would-be vulcanoid belt, which may eventually be able to establish stricter limits on the significance of this putative population of small bodies.

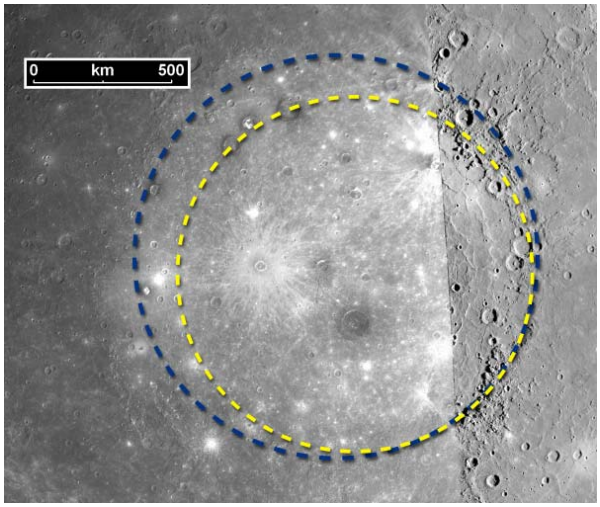

Fig. 1. The Caloris basin (Mariner 10 image on the right, MESSENGER image on the left) and early and recent diameter estimates.

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